Att. #7

Not Enter. HP 7/29/98

Utility Patent Application of ALEKSANDR L. YUFA

for

METHODS AND DEVICE FOR COUNTING AND MEASURING PARTICLES

FIELD OF THE INVENTION

This invention relates to air and liquid quality and, more particularly, to devices and instruments for particle quantity counting and particle size measuring by light or laser beam.

BACKGROUND OF THE INVENTION

The methods and devices for determining quantity and size of the particles and small bodies are now well known, and it is also well known that powerful light or laser and optical system or mirror can be, and have been, heretofore used to achieve particle size and particle quantity measurements. Such devices are well known and described in the articles: R.G.Knollenberg, B.Schuster--"Detection and Sizing of Small Particles in Open Cavity Gas Laser," Applied Optics, Vo.11, No.7, November 1972, pp.1515-1520; R.G.Knollenberg--"An Active Scattering Aerosol Spectrometer," Atmospheric Technology, No.2, June 1973, pp.80-81; Schehl, Ergun, Headrick--"Size Spectrometry of Aerosols Using Light Scattering from the Cavity of a Gas Laser," Review of Scientific Instruments, Vol. 44, No. 9, September 1973; R.G.Knollenberg--"Active Scattering Aerosol Spectrometry," National Bureau of Standards Special Publication, No.412, October 1974, pp.57-64; R.G.Knollenberg, R.E.Luehr--"Open Cavity Laser 'Active' Scattering Particle Spectrometry from 0.05 to 5.0 Microns," Fine Particles, Aerosol Generation Measurement,

Sampling and Analysis, Academic Press, May 1975, pp.669-696; R.G.Knollenberg--"Three New Instruments for Cloud Physics Measurements: The 2-D Spectrometer, the Forward Scattering Spectrometer Probe, and the Active Scattering Aerosol Spectrometer", American Meteorological Society, International Conference on Cloud Physics, July 1976, pp. 554-561; R.G.Knollenberg --"The Use of Low Power Laser in Particle Size Spectrometry", Proceeding of the Society of Photo-Optical Instrumentation Engineers, Practical Applications of Low Power Lasers, Vo.92, August 1976, pp.137-152; Elterman--"Brewster Angle Light Trap," Applied Optics, Vol. 16, No. 9, September 1977; Marple--"The Aerodynamics Size Calibration of Optical Particle Counters by Inertial Impactors," Aerosol Measurement, 1979; Diehl, Smith, Sydor--"Analysis by Suspended Solids by Single-Particle Scattering," Applied Optics, Vol. 18, No. 10, May 1979; K.Suda--Review of Scientific Instruments, Vol. 51, No. 8, August 1980, pp.1049-1058; R.G.Knollenberg--"The Measurement of Particle Sizes Below 0.1 Micrometers", Journal of Environment Science, January-February, 1985, pp. 64-67; Peters--"20 Good Reasons to Use In Situ Particle Monitors", Semiconductor International, Nov. 1992, pp.52-57 and Busselman et al.--"In Situ Particle Monitoring in a Single Wafer Poly Silicon and Silicon Nitride Etch System", IEEE/SEMI Int'l Semiconductor Manufacturing Science Symposium, 1993, pp.20-26.

The reference in these articles is made to the devices and methods of particle measurement utilizing an open cavity laser. These methods and devices use imaging systems, which are based on lens use (Fig.1), the same as it mentioned, for example, in U.S. Patent No. 4,140,395, U.S.

Patent No.4,798,465 and in U.S. Patent No. 5,495,105 of the prior art.

The other devices mentioned in prior art (for example, U.S. Patent No. 4,606,636) use a non-divergent quadric reflector (Fig.2). Such devices use a paraboloidal sphere as mirror.

Yet in other prior art (for example, such as U.S. Patent No. 4,189,236, U.S. Patent No. 4,523,841, U.S. Patent No. 5,467,189 and U.S. Patent No. 5,515,164) we can find the devices (sensors) with ellipsoidal mirrors (Figs.3, 4) instead of the lens systems or non-divergent quadric mirrors.

All these devices, mentioned in the prior art above, use light scattering focalizing methods. Such methods are based on the collection of the scattered light. A light scattering occurs at the first focal point (focus) by particles in the laser beam. Considering stochastic dispersion of the scattered light, the devices, mentioned in the above prior art, use mirrors or optics. This is necessary for scattered light collecting and focalizing at the second focal point (focus), where a light detector is placed and intended for scattered light detection.

Another known method uses direct detection, as it mentioned in U.S. Patent No.5,085,500. By this method, the scattered light in such devices is detected by the light detectors directly with no scattered light collection system (Fig.5).

As shown on Fig.1, related to the use of the optics, regarding the U.S. Patents No.4,140,395, No. 4,798,465, and No. 5,495,105, the scattered light 6 is collected by the optical system 10, which is presented by the lenses.

On Fig.2 is presented the device, using non-divergent quadric mirror, (U.S. Patent No.

4,606,636). From Fig.2 we see that the collection of the scattered light is provided by non-divergent quadric mirror 18.

The counting and measuring devices (sensors), mentioned in the U.S. Patents No. 4,189,236, No. 4,523,841, No. 5,467,189, and No. 5,471,299, using an ellipsoidal mirrors 17, are presented on simplified Fig.3.

On Fig.4 is presented the particle sensor by U.S. Patent No. 5,515,164, also using the ellipsoidal mirror for the scattered light collection. This sensor uses specially ~~especially~~ increased cross-section outlet area of the particle flow.

On Fig.5 is shown a simplified drawing of the device, using the direct detection method.

It is understood, that the methods and devices, mentioned of the prior art of the above, require the use of the scattered light collection means and systems (Figs.1-4) or very large spatial surface of the light detector or sufficient quantity of the light detectors (Fig.5). Such methods and/or devices need to include expensive means and systems. Also, the mentioned above methods and devices have a common deficiency, which is characterized by ~~contained in the~~ non-consideration of all scattered light plurality (for example, a scattered light 23 on Figs.1-5) and non-precise focalizing of the particle flow (for example, a scattered light 7 on Figs.1-5).

It is known, that integrated circuits (chips) and semiconductors have been produced in "clean rooms". The air in such "clean rooms" should be very well cleaned. The continuing tendencies of improvement in circuit integration and degree of microminiaturization require corresponding

improvements of the environment in "clean rooms" and efficiency of the measuring devices. And now, as known from prior art, the sensitivity of the counting and measuring devices should be at least as small as $0.1\mu m$ (Micron).

Other known devices use a fiber optic means for scattered or diffracted light collection (see, for example, U.S. Patents No.4,595,291, No. 5,325,169, No.5,619,333 and No.5,731,875). Some known devices (for example, by U.S. Patent No.5,731,875) use a plurality of light emmiting lasers intended for the power decreasing, that provides the eliminating of the laser heat-sink, but, it requires to use a plurality of fiber optic stands and the optical element(s) for the focusing of a plurality of light beams.

Thus, the unfocused and/or unconsidered (undetected) scattered light in the mentioned above devices of a prior art creates light background (light noises) inside such devices, creating thereby incorrectness of the resulting information about the measured environment. Additionally, such light noises limit the sensitivity of the counting and measuring devices.

Also the devices, based on scattered light collection and some other detection methods (for example, by light splitting or by direct detection), use a different variations of the analog comparison method for the particle size measuring. Such method can be illustrated, for example, by U.S. Patent No.4,798,465, wherein is shown the particle size detection device, using one of the particle measuring comparison method variations. The signal from detectors via the amplifiers follow to the comparators, which are connected to the reference voltage means. The amplified detected

signals are compared with the predetermined different reference voltages for the particle size qualifying.

The same analog comparison methods we can find in the U.S. Patents No. 5,325,169 and No. 5,619,333.

Such methods cannot provide a sufficiently high sensitivity related to the increasing environmental requirements, because of the non-precise analog method of comparison.

OBJECT AND ADVANTAGES OF THE INVENTION

Accordingly, several objects and advantages of the present invention are to provide an improved methods and device for counting and measuring particles.

It is another object of the invention to provide an improved method and device for increasing the precision of particle counting and measuring.

It is still another object of the invention to provide an improved method and device for increasing the efficiency of the measuring and counting process.

It is still further an object of the invention to provide an improved method and device for increasing the authenticity of the information about air or liquid composition.

It is yet another object of the invention to provide an improved method and device for decreasing light noises by the elimination of unfocused and/or unconsidered scattered light.

It is another further object of the invention to provide an improved method and device for increasing sensitivity of the particle size detection by the elimination of the scattered light collec-

tion.

Still, further objects and advantages will become apparent from a consideration of the ensuing description accompanying drawings.

DESCRIPTION OF THE DRAWING

Fig.1 is a presentation of the scattered light collection by an optics in the prior art devices.

Fig.2 is a presentation of the scattered light collection by a non-divergent quadric mirror in the prior art devices.

Fig.3 is a presentation of the scattered light collection by an ellipsoidal mirror in the prior art devices.

Fig.4 is a presentation of the scattered light collection by an ellipsoidal mirror with the especially increased inlet cross-sectional area of the particle flow in the prior art devices.

Fig .5 is a presentation of the scattered light direct detection method in the prior art devices.

Fig.6 is a presentation of the simplified drawing of the light detecting system of the improved method and device for airborne particles.

Fig.7 is a presentation of the structural schematic of an improved device.

Fig.8 is a presentation of the block-schematic of an improved device.

Fig.9 is a presentation of the signal timing-diagram.

Fig.10 is a representation of the structural schematic of an improved device with a remote light beam source.

SUMMARY OF THE INVENTION

The invention provides a method and device, having a high sensitivity and a precision of counting and measuring particles, wherein a particle size sensitivity achieves at least as small as 0.1 μm. An improved method of counting and measuring particles forms direct detection processes, eliminating the light scattering detection principles. An improved device, realizing the improved direct detection method, includes a light detecting system and a processing system, including an analog-digital subsystem and a control subsystem. A light or laser beam intersects a particle flow inside a light detecting system in the light detection means area. The light detection means is placed on the light beam axis. The signals, detected by light detection means, through an analog-digital subsystem follow to a processing system for signal processing and information displaying. The improved methods and device provide the direct detection of the particles and timing processing of the detected signals.

By an improved method, the improved timing processing of the detected signals is provided by strobing the digital form pulses created from the appropriate amplified detected signals, having the different durations created by aproppriate different size particles, intersecting the light beam.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Here the description of an improved method and device will be done in statics (as if the components of the improved device are suspended in the space) with description of their relative

locations and connections to each other. The description of the improved processes and functional operations of an improved device will be done hereafter.

Referring to Figs.6, a light detecting system 11 includes a chamber 12, a light beam along axis 2 (a laser beam can be used), a particle flow along axis 3, a light detection means 4 and a particle flow tubular means 26. For example, the particle flow tubular means 26, intended for analyzing of the airborne particles, is interrupted in the light detection means 4 area, as it is shown on Fig.6. A chamber 12 of the light detecting system 11 has black flat (rough) inside coating, absorbing possible reflected light and eliminating thereby possible light background (light noises).

On Fig.7 is shown the structural schematic of an improved device, including a light detecting system 11, connected to an analog-digital subsystem 14 of a processing system 27. The analog-digital subsystem 14 is connected to a control subsystem 13 of a processing system 27. The control subsystem 13 includes a microprocessor subsystem 20 and a terminal means 21.

On Fig.8 is shown the portion of an improved device, which realizes an improved timing processing method of the detected signal. Referring to Fig.8, a light detection means 4 of the light detecting system 11 is connected to a current-voltage conversion means 19 (if the primer signals from the light detection means 4 are presented in the current value). The current-voltage conversion means 19 of the analog-digital subsystem 14 is connected to an amplifying means 22, which is connected to a analog-digital pulse duration conversion means 24. The analog-digital pulse duration conversion means 24 is connected to a conjunction means 30, which is connected

to a strobe pulse generating means 31 (for example, a controlable oscillator). Also the strobe pulse generating means 31 and the conjunction means 30 are by multiplexed bus 25 connected to a selecting, sorting and counting means 32 of the microprocessor subsystem 20 of the controil system 13.

Fig.9 presents a timing diagram of the signal processing. On this figure τ_i represents a duration of the pulses, where i = 1, 2, 3, ...

Fig.10 is presented a structure of an improved device with a remote light beam source. A remote light beam source 28, connected by a fiber optic connecting means 29 to a light detecting system 11, which is connected to a processing system 27, including an analog-digital subsystem connected to a control subsystem 13, comprising a microprocessor subsystem 20 and a terminal means 21.

An improved device operates as follows. The light or laser beam along axis 2 intersects a particle flow along axis 3 in the area of a light detection means 4, placed on a light beam axis 2, as shown on Fig.6. When the particles of the particle flow intersect the light beam, the intensity of the light beam on the light detection means 4 will be less than at the time when the particles are missing, because the presence of a particle in the light beam obstructs the light to the light detection means 4. For other detecting principles (for example, for scattered light detection by mirror collecting system), the intensity of light beam on the light detection means (on the light detector) will be higher than at the time when the particles are missing.

The signals detected by the light detection means 4, (see Fig.8) follow to the current-voltage

conversion means 19 of the analog-digital subsystem 14 of a processing system 27.

The detected signals can be described by an equation **I** = f_1 **(E, F$_1$)**, where: **I** - an output current of the light detection means 4 (if the primer signals from the light detection means 4 are the current value signals); **E** = f_2 **(P, D, F$_2$)** - a light intensity of the light beam on the light detection means 4; **P** - an unabstructed light beam power, **D** - a particle dimensions (sizes), **F$_2$** - the other factors (for example, a particle reflectiveness, a particle permeability, etc.); **F$_1$** - a physical-technical parameters of the light detection means 4.

The signals from the light detection means 4 follow, as was mentioned above, to the current-voltage conversion means 19, where they are conversed to the voltage value signals, as shown on Fig.9a (for other detecting principles, for example, for scattered light detecting principles, the signals can have a positive polarity), and after the amplifying (Fig.9b) by an amplifying means 22 they follow to the analog-digital pulse duration conversion means 24. The analog-digital pulse duration conversion means 24 provides two major operations: converses the analog form pulses to the digital form pulses and converses the duration of analog pulses to the adequate duration of digital pulses.

From the analog-digital pulse duration conversion means 24 the signals (Fig.9c) follow to the conjunction means 30, in which also follow strobe pulses (Fig.9d) from the strobe pulse generating means 31. The signals (Fig.9e) from the conjunction means 31, having the strobe pulse packages configuration, follow to the selecting, sorting and counting means 32 of the microprocessor

subsystem 20 of the control system 13.

The selecting, sorting and counting means 32 provides selection and sorting of the identical strobe pulse packages (packages within same strobe pulse quantity, that means - with the same strobe pulse package duration τ_i, where i = 1, 2, 3, ...) and also provides the counting of the identical strobe pulse packages, determining a particle quantity, and the counting of the strobe pulse quantity in the mentioned packages, determining a particle size. The processed signals (packeges, see Fig.11e) have the different durations τ_i. These durations are related to the different sizes of the particles, which create the different obstructions for the light beam. The durations τ_i, characterize the particle sizes. The longer strobe pulse package (the bigger value of τ_i), the bigger particle size. The higher frequency of the strobe pulses, the higher precision and sensitivity of an improved device:

$$S = f\,(F_P) \qquad [1]$$

and

$$S \rightarrow \left| \begin{matrix} 0 \\ \infty \end{matrix} \right. \Rightarrow \begin{cases} F_P \rightarrow 0 \\ F_P \rightarrow \infty \end{cases}, \qquad [2]$$

where S - a sensitivity;

f - a functional symbol (a function);

F_P - a strobe pulses frequency.

Also the microprocessor subsystem 20 processes, for example, the signals, containing the information, for example, about environmental temperature, humidity, velocity rate, etc.

The microprocessor subsystem 20 is also connected by the multiplexed bus 25 to a terminal means 21, which can include a display means, a printing means, a compact disc means, a floppy disc means and an external interface means (all of them not shown). The control subsystem 13 also includes the self-diagnostic and calibration means (not shown), connected to an analog-digital subsystem 14 and by multiplexed bus 25 to the microprocessor subsystem 20.

Referring to Fig.10, the light beam or laser beam is transferred from a remote light beam source (or remote laser beam source) 28 to the chamber 12 (see on Fig.6) of a light detecting system 11 by a fiber optic connecting means 29.

CONCLUSION, RAMIFICATION AND SCOPE

Accordingly the reader will see that, according to the invention, I have provided a precise and effective method and device, which provides counting and measuring of all particles of the assayed air (gas) or liquid. An improved methods and device provide authenticity of the real quantity and size of the particles in the assayed mixture of air, gas or liquid.

Also the improved methods and device provide correctness of the resulting information, because the light noise (light background) inside an improved device is eliminated.

While the above description contains many specificities, these should not construed as limita-

tions on the scope of the invention, but as exemplification of the presently-preferred embodiments thereof. Many other ramifications are possible within the teaching of the invention. For example, an improved method and device provide authentic counting and measuring of particles, because very precise focusing of the mirrors or optics is not required. The procedure of periodical calibration is much easier for an improved timing processing of the detected signals, because an improved method and device does not require the consideration of the light background (created by unfocused and/or unconsidered scattered light, as it is presented in the known prior art, mentioned above). An improved timing processing of the detected signals provides unlimited sensitivity of the improved device and eliminates necessity of the periodical calibration by manufacturer. Also an improved device uses a single small light detector and does not require a power light beam for creating a scattetred light.

Thus, the scope of the invention should be determined by the appended claims and their legal equivalents, and not by examples given.